Lightning Protection Design and Certification of Small Airplanes Employing Composite Materials and Modern Avionics

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Topics

- Regulations and Policies
- Advisory Material and the Environment
- Failure Condition Classification
- Verification Test Standards
- Protection Design Guidelines and Data
- Equipment Transient Control and Design Levels
- Verification Tests

Regulations and Policies

FAR/JAR 23.867, Lightning Protection

This is the top level requirement that requires that the airplane not experience catastrophic damage as a result of a lightning strike.

This has usually been interpreted as meaning that the air vehicle must be able to continue safe flight to a safe landing following an in-flight strike.

FAR/JAR 23.954, Fuel System Lightning Protection

This requires that fuel system be designed to prevent the ignition of fuel vapor as a result of a lightning strike.

This is usually accomplished by elimination of lightning-related ignition sources (i.e. arcs, sparks and hot spots) from within the fuel system.

FAR 23.1309, Equipment, Systems and Installations

(b) The design of each item of equipment, each system, and each installation **must be examined** …..to determine if the airplane is dependant upon its function for continued safe flight and landing…(or for IFR airplanes)…if failure of a system would significantly reduce the capability of the airplane or ability of the crew to cope with adverse operating conditions. (**Each item so identified):**

- **Must perform its intended function under any forseeable operating condition**

(2)(i) …..**any failure condition that would prevent continued safe flight and landing….must be extremely improbable, and**

(ii) ….**any other failure condition that would significantly reduce (capabilities of airplane or crew) to cope with adverse operating conditions must be improbable.**

- Warning information must be provided to alert the crew to unsafe….conditions must be improbable

(e) **In showing compliance**…with regard to….power system and…equipment design and installation……..**the effects, (both direct and indirect) of lightning must be considered.** (Amdt. 23-41, 1990)

FAR 33.28, Electrical and Electronic Engine Control Systems

This regulation requires that electronic control systems be designed and constructed so that any failure of aircraft-supplied power or data does not prevent continued safe operation of the engine, and so that any single failure or combination of failures not result in an unsafe failure condition.

It also requires that the engine equipment transient design levels (ETDLs) be specified in the instruction manual.

Advisory Material

FAA AC 20-53A, Protection of Airplane Fuel Systems Against Fuel Vapor Ignition Due to Lightning

This AC describes a means for showing compliance of fuel systems with FAR/JAR/TAR 25.954. It also defines the external lightning environment, and provides lightning strike zone definitions and location guidelines (**but these materials are out of date)**.

Since no FAA AC exists for airframes and structures, the guidelines in AC 20-53A have been used in a general way to guide certification of airframe and structures designs, including engine nacelles. Soon, EUROCAE and SAE will take up the task of preparing new routes to compliance for lightning direct effects certification.

Lightning Environment

The lightning environment is defined in EUROCAE Report ED-14 and SAE ARP 5412 **"Aircraft Lightning Environment and Related Test Waveforms".**

Applicability of this environment is in accordance with the lightning strike zones associated with each individual airplane. The zones and the applicable lightning environment components are defined in EUROCAE Report ED-91 and SAE ARP 5414 **"Aircraft Lightning Zoning".**

Briefly, this means that the exterior surfaces must tolerate the arc- entry and conduction effects of current Component A (200 kA, 2 x 10^6 A^2s) together with the effects of the intermediate and continuing currents, Components B and C.

The structures in Zone 3 must withstand the direct and indirect effects of the Zone 3 currents being conducted through them.

The External Lightning Environment is the Same for all Aircraft:

- Therefore the **lightning current densities** (A/cm^2) in small airplane structures are much higher than in structures of large airplanes.
- Similarly, the **magnetic field intensities**, H (A/m) surrounding small airframes are higher than are the magnetic fields around large airplanes. A factor of 8:1 is not uncommon.
- This means the possibilities for lightning related **physical damage** of airplane structures, and for hazardous lightning **induced effects in electrical/avionics systems** are greater in small airplanes than in large airplanes.

Some Misconceptions:

- That a small airplane should be able to certify to a lower intensity external lightning environment than is required for a large airplane (the Regulations and ACs don't say or imply this).
- That, because they often fly at lower altitudes, the intensities of lightning strikes that hit small airplanes can be assumed to be lower than those that are encountered by larger airplanes that operate at higher flight altitudes (the opposite is true: stroke current intensities are highest nearer the earth in cloud-earth flashes).
- That the lightning protection regulations (i.e. FARs/JARs) applicable to small airplanes ("…must not experience catastrophic effects…") are less stringent than those applicable to large transport category airplanes (the Regulations and ACs do not say or imply this).

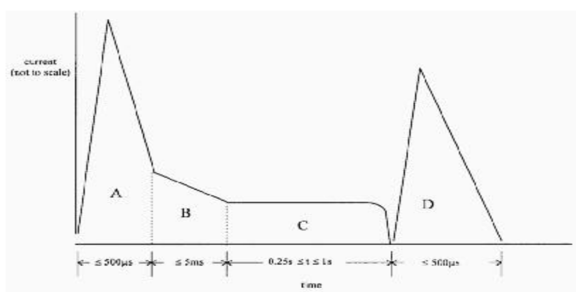
Airplane Lightning Environment

Is defined in SAE ARP5412 "Aircraft Lightning Environment"

- Component A: 200 kA, $2x10^6$ A^2s
- Component B: 2 kA (Avg), 10 Coulombs charge transfer
- Component C: 200 A for 1s, transferring 200 Coulombs
- Component D: 100 kA, $0.25x10^6$ A^2s

Updates criteria in FAA AC 20-53A and the SAE "Blue Book"

External Lightning Environment for Direct Effects Evaluations



COMPONENT A (First Return Stroke)

Peak Amplitude	:	200kA (± 10%)
Action Integral	:	$2 \times 10^6 A^2s$ (± 20%) (in 500μs)
Time Duration	:	≤ 500μs

COMPONENT B (Intermediate Current)

Max. Charge Transfer	:	10 Coulombs (± 10%)
Average Amplitude	:	2kA (± 20%)
Time Duration	:	≤ 5ms

COMPONENT C (Continuing Current)

Amplitude	:	200 - 800A
Charge Transfer	:	200 Coulombs (± 20%)
Time Duration	:	0.25 to 1 s

COMPONENT D (Subsequent Return Stroke)

Peak Amplitude	:	100kA (± 10%)
Action Integral	:	$0.25 \times 10^6 A^2s$ (± 20%) (in 500μs)
Time Duration	:	≤ 500μs

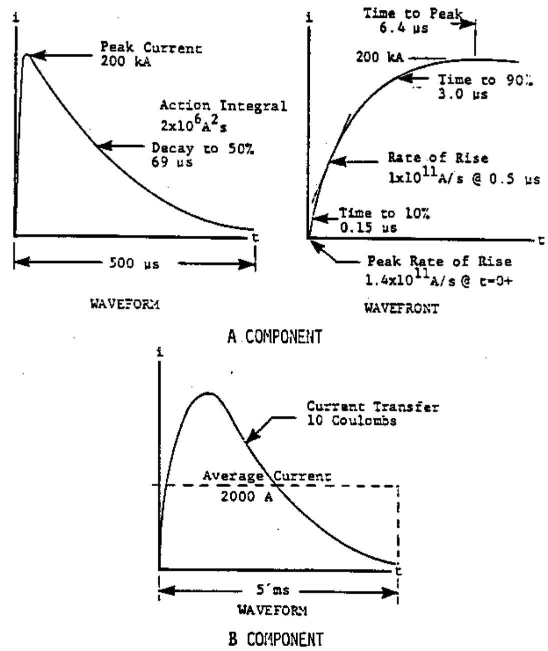


Figure AIII-1. Waveforms of Current Components A and B

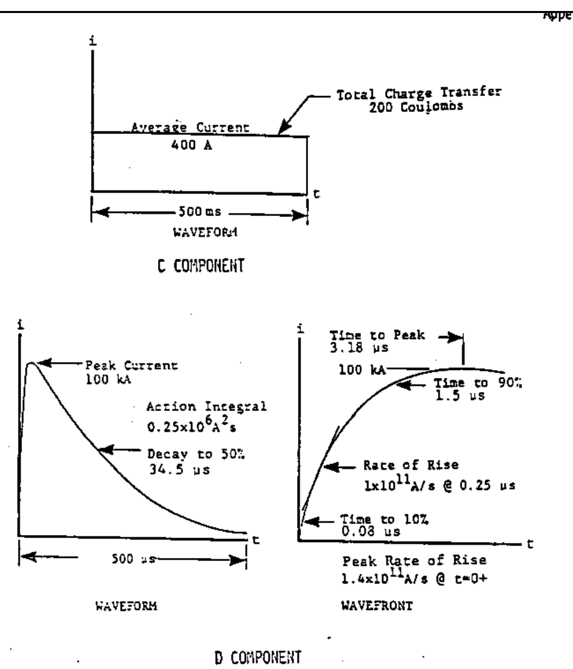


Figure AIII-2. Waveforms of Current Components C and D

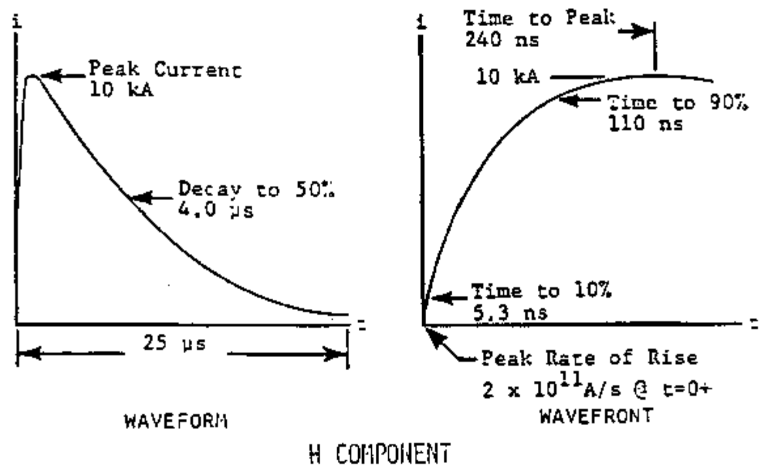
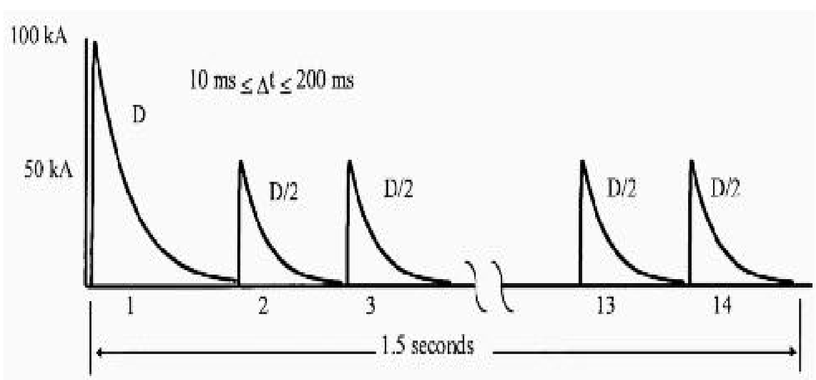
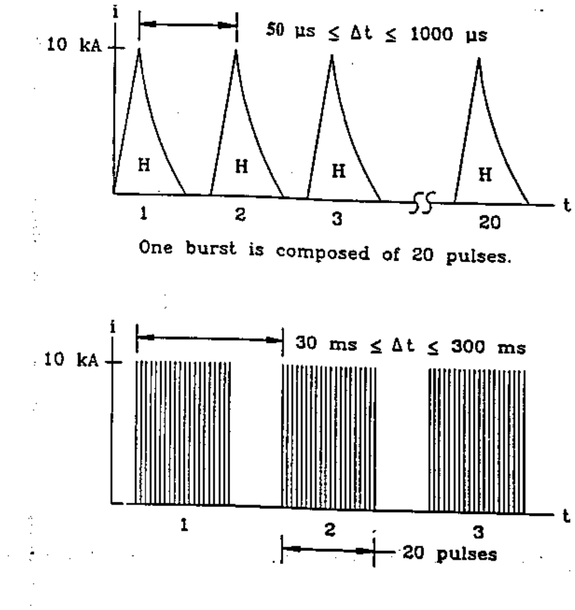


Figure AIII-3. Waveform of Current Component H

Multiple Stroke waveform Set



One current component D followed by thirteen current component D/2s distributed over a period of up to 1.5 seconds.



REVISED MULTIPLE BURST WAVEFORM

Current Components Applicable in Various Zones

Zone	A	B	C	D	Multiple Stroke	Multiple Burst
1A	X	X			X	X
1B	X	X	X	X	X	X
2A		X		X	X	X
2B		X	X	X	X	X
3	X	X	X	X	X	X

Ref: AC 20-136, Table AIII-2

FAA Advisory Circular AC 20-136, Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning, dated 3 May 1990

This AC provides a **means for showing compliance** with FAR/JAR 25.1309 and 25.1316 pertaining to protection of electrical/electronic systems against the indirect effects of lightning. It also contains the **external lightning environment** and a **menu of typical lightning-induced transient waveforms and levels** for use in assigning equipment transient design levels (ETDLs) to individual pieces of electrical or avionic equipment.

A proposed revision of this AC has been published by EUROCAE WG-3 as **ED-81** and by SAE as Aerospace Recommended Practice **(ARP) No. 5413.**

An updated Lightning Environment is found in SAE ARP 5412/EUROCAE ED 14

SAE ARP 5413 and EUROCAE Report ED-81 "Certification of Aircraft Electrical/Electronic Systems for the Indirect Effects of Lightning"

This is the proposed revision of FAA AC 20-136.

It provides more specific routes-to-compliance, tailored to the function being performed by the system being certified.

It also deletes lightning environment and zoning information that presently exists in AC 20-136. JAA has issued INT/POL/25/4 authorizing use of these revised procedures on 1 Jan. 2000.

It is expected that FAA will issue a similar policy directive

Failure Condition Classifications, Hazard Levels, and Protection Considerations

Failure condition classifications are derived from the Functional Hazards Assessment **(FHA)** and represent the top-level pass/fail performance criteria for an aircraft function.

These criteria provide the information from which system and equipment performance pass/fail criteria can be derived.

The system and equipment pass/fail criteria can be used subsequently during compliance/qualification activities.

Hazard Conditions

Catastrophic: Failure conditions which would **prevent continued safe flight and landing.**

Hazardous/Severe-Major: Failure conditions which would **reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions** to the extent that there would be:

- (i) A large reduction in safety margins or functional capabilities
- (ii) Physical distress or higher workload such that the flight crew could not be relied upon to perform their tasks accurately or completely, or
- (iii) Serious (or fatal*) injury to a relatively small number of occupants

* JAA only

Hazard Conditions (Cont'd)

Major: Failure conditions which would **reduce the capability of the aircraft or the crew to cope with adverse operating conditions** to the extent that there would be, for example, a significant reduction in safety margins or functional capabilities, a significant increase in crew work load or in conditions impairing crew efficiency, or discomfort to occupants, possibly including injuries

Minor: Failure conditions which would **not significantly reduce aircraft safety**, and which involve crew actions that are well within their capabilities. Minor failure conditions may include, for example, a slight reduction in safety margins or functional capabilities, a slight increase in crew workload, such as routine flight plan changes, or some inconvenience to occupants.

No effects: Failure conditions which **do not effect** the operational capability of the aircraft or increase crew workload.

Development Assurance Levels

Level A: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a **catastrophic failure condition**

Level B: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a **hazardous/severe major failure condition**

Level C: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a **major failure condition**

Level D: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in a **minor failure condition**

Level E: Electrical and electronic systems whose failure would cause or contribute to a failure of function resulting in **no effect on aircraft operability or pilot workload**

Thus there are four Development Assurance levels of rigor relative to function being performed by a system:

- Level A control
- Level A display
- Level B
- Level C

Table 1 shows a cross reference between AC 23.1309-1C, 25.1309-1A and the nomenclature used in the ARP5413, derived from ARP4754.

TABLE 1 - Nomenclature Cross Reference

Failure Condition Classification (AC 23.1309-1C, AC 25.1309-1A and ARP4754)	System Development Assurance Level (ARP4754)
No Effect	Level E
Minor	Level D
Major	Level C
Severe Major/Hazardous	Level B
Catastrophic	Level A

Level A Requirements

The primary concern is the continuation of the Level A function in flight without adverse effects. Any susceptibility cannot affect the safe operation of the aircraft.

Level A functions are further categorized into two groups. One group involves functions for which the pilot will not be part of the operational loop. These are classified as **Level A control** function, i.e. FBW, FADEC. FADEC and FBW controls are classified as Level A functions.

The second group involves functions for which the pilot will be within the loop through pilot/system information exchange. These are defined as **Level A display** functions, i.e. EFIS, EICAS.

Level A Control Systems

Methods of achieving compliance of Level A control systems to lightning protection requirements are outlined in ARP 5413.

Level A controls require the most rigor in showing compliance. This method can also be used for all other function classifications.

One such system is the Automatic Flight Control System (AFCS). The term "Automatic Flight Control" is commonly used to define systems which perform a controlling function with respect to one or more of the primary axes of pitch, roll, or yaw of the aircraft in flight. The systems which perform these controlling functions are AFCS and FBW Flight Control Systems.

Level A Display Systems

Methods of achieving compliance of Level A display systems to lightning protection requirements are outlined in ARP5413.

Based upon the fact that **Display Systems** failures and malfunctions do not contribute as directly or as abruptly to catastrophic failures as do control systems failures, a **less rigorous verification method is provided.**

Level A display systems perform functions with failure condition classifications considered to be catastrophic. However, for the Level A Displays, the flight crew is in the loop and the catastrophic event is a result of some action taken by the crew as a result of hazardously misleading or missing information provided by the display.

Level B and Level C Requirements

The aircraft test or analysis methods used to determine the TCLs and ETDLs for Level A systems are also acceptable for the determination of TCLs and ETDLs for Level B and C systems.

Alternately, Level 3, as defined in D0-160D/ED Section 22, may be used for most Level B systems.

For Level B systems and associated wiring installed in more severe electromagnetic environments such as areas with poor shielding effectiveness, a higher level may be appropriate.

Verification Test Standards

Test Standards

SAE AE4L Report AE4L-78-1, Lightning Test Waveforms and Techniques for Aerospace Vehicles and Hardware

This is the present Standard for Lightning **Direct Effects** Certification Tests

Applicable to Airframe and Structural Elements, Fuel Tanks and Systems, Control Surfaces, Radomes, Windshields, and other items exposed to direct lightning strike or current conduction effects

This standard is being updated by SAE and EUROCAE

RTCA-DO-160D/EUROCAE-ED-14, Environmental Conditions and Test Procedures for Airborne Equipment

Section 22: Lightning Induced Transient Susceptibility

This test standard is applicable for verifying the capability of equipment to withstand the effects of lightning-induced transients. It is applied to verify damage tolerance of electrical and electronic equipment.

Section 23: Lightning Direct Effects

This test standard is for verifying ability of externally mounted equipment, such as lights and antennas, to tolerate the physical damage effects of lightning strikes.

RTCA DO-160D, Section 22 Table of Contents

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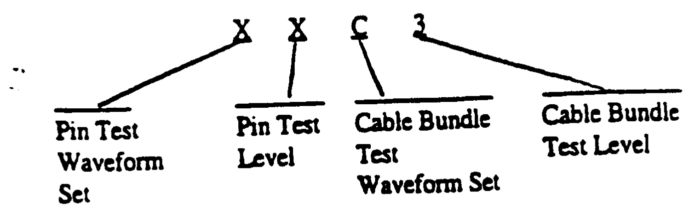
Category designation should, therefore, appear as follows:



Ref. RTCA DO-160D

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Equipment Damage Tolerance Test levels

Table 22-2 Test Levels for Pin Injection

Level	Waveforms 3	4	5A
	Voc/Isc	Voc/Isc	Voc/Isc
1	100/4	50/10	50/50
2	250/10	125/25	125/125
3	600/24	300/60	300/300
4	1500/60	750/150	750/750
5	3200/128	1600/320	1600/1600

System Functional Upset Test levels

Table 22-3 Test Levels for Cable Bundles

Level	Waveforms 1	2	3	4	5A
	V_L/I_T	V_T/I_L	V_T/I_L	V_T/I_L	V_L/I_T
1	50/100	50/100	100/20	50/100	50/150
2	125/250	125/250	250/50	125/250	125/400
3	300/600	300/600	600/120	300/600	300/1000
4	750/1500	750/1500	1500/300	750/1500	750/2000
5	1600/3200	1600/3200	3200/640	1600/3200	1600/5000

DO160D section 22, Table 22-1

Waveform Set	Test Type	Test Levels	Waveform Nos.	Test Method	Notes
A	Pin	Table 22-2	3, 4	22.5.1	1
B	Pin	Table 22-2	3, 5A	22.5.1	1
C	Cable Bundle (Unshielded)	Table 22-3	2, 3	22.5.2.1	2, 5
			4	22.5.2.2	
D	Cable Bundle (Unshielded)	Table 22-3	2, 3	22.5.2.1	2, 3, 5
			5A	22.5.2.2	
E	Cable Bundle (Shielded)	Table 22-3	1, 3	22.5.2.1	2, 4, 5
F	Cable Bundle (Shielded)	Table 22-3	3	22.5.2.1	2, 5
			5A	22.5.2.2	

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Design Guidelines and Data

Design Guidelines and Data

From an SBIR Program:

LIGHTNING AND HIGH INTENSITY RADIATED FREQUENCY
PROTECTION DESIGN GUIDELINES AND DATA
FOR
AVIONIC SYSTEMS FOR SMALL AIRPLANES

Conducted by Lightning Technologies, Inc.
under an SBIR
Sponsored By
National Aeronautics and Space Administration
Langley Research Center

The SBIR Purpose:

To provide **design guidelines and data** for protection of avionic systems in small general aviation aircraft exposed to lightning and high intensity radiated frequency (HIRF) environments, as defined in the FAA advisory circulars and other standards applicable to airworthiness certification of small airplanes.

The Lightning Induced Transients and HIRF field data were taken in a **Mooney Model 205 Fuselage** test bed.

Direct and Indirect Effects

The guidelines from the NASA SBIR address primarily the **indirect effects** on electrical and avionic systems.

If an avionic system includes externally mounted components such as **COM** and **NAV** antennas or **air data probes**, these devices are exposed to the effects of direct lightning attachments in accordance with the zones in which the devices are located.

If continued function of externally mounted components is required to meet avionics certification requirements, they **must be protected against the direct effects** of lightning attachment **as well as the lightning indirect effects.**

Indirect Effects Coupling Mechanisms: Structural IR Voltages

The structural voltages are the product of structure resistances (R) and currents (I) and hence referred to as "structural IR voltages".

The time domain waveshape of these voltages is the same as the lightning stroke current Component A as defined in the lightning environment standard.

Indirect Effects Coupling Mechanisms: Magnetic Fields

The internal magnetic fields are due to penetration of external fields directly through **apertures** (“aperture” fields), and to **diffusion** and **redistribution of current** to internal conducting elements.

These fields have longer rise and decay times than the lightning current, and so are usually less important than the aperture fields.

The aperture fields also have the same waveshape as the lightning stroke current, Component A.

The voltages induced by changing aperture fields in aircraft circuits are proportional to the rates of change, dH/dt, of the aperture fields.

Voltages Induces by Magnetic Fields:

$$V_{oc} = \mu_o A \, dH/dt$$

where;

Voc = the loop voltage, called Voc, viewed at an open end of the loop (volts)

μ_o = permeability of free space $= 4\Pi \times 10^{-7}$ Henries/meter

A = area of the loop (m^2)

H = magnetic field intensity (A/m)

Actual Transient Levels in the Mooney Fuselage

Measurements of lightning-induced voltages and currents in typical circuits within the Mooney fuselage were made to help establish recommended ETDLs for equipment and systems to be installed within other small aircraft of similar size and construction.

Twenty-three (23) wire harnesses and/or test conditions were measured. All were measured with current Component A conducted through the fuselage and most were measured during tests applying current Waveform H, as well.

Actual Transient Levels in the Mooney Fuselage

Table 5-4. Lightning-induced Voltages and Currents in Typical Wires and Cables within the Mooney Fuselage

Group or Test No.	Wire Routing	Fuselage Configuration	Induced by A		Induced by H	
			Voc	Isc	Voc	Isc
1	2" x 27" wire loop on cabin floor at pilot seat location	Doors closed	40 WM1-V/A	64 WM1-I/A	36 WM1-V/H	3.1 WM1-I/H
2	Wire from aft equipment bay to MFD, route LH lower harness	Access panel removed	168 WM2-V/A	110 WM2-I/A		
2, 11, 12	Wire from aft equipment bay to MFD, route LH lower harness	Access panel in place	158 WM2-V/A	110 WM2-I/A	109 WM12-V/H	3.3 WM11-I/H
3, 9	Wire from tail to MFD, route upper harness	Doors closed	286 WM3-V/A	42 WM3-I/A	322 WM9-V/H	5 WM9-I/H
4, 7	Wire from pilot side of engine to MFD, route with unshielded harness	Cowling removed	8600 WM4-V/A	7000 WM4-I/A	13,900 WM7-V/H	450 WM7-I/H
13, 14, 17	Wire from pilot side of engine to MFD, route with unshielded harness	Cowling in place	8000 WM17-V/A	7000 WM17-I/A	11,800 WM13-V/H	402 WM14-I/H
5, 6	Wire from co-pilot side of engine to MFD, routed with shielded engine harness	Cowling removed	1140 WM5-V/A	2200 WM5-I/A	1240 WM6-V/H	87 WM6-I/H
15, 16	Wire from co-pilot side of engine to MFD, routed with shielded engine harness	Cowling in place	1220 WM16-V/A		1260 WM15-V/H	87 WM15-I/A
22, 23	Wire, shielded, from pilot side of engine to MFD	Doors closed	548 WM23-V/A	2200 WM23-I/A	87 WM22-V/H	54 WM22-I/H
18, 20	Wire from co-pilot side of instrument panel to MFD, routed underneath instrument panel	Doors closed	70 WM18-V/A	70 WM18-I/A	67 WM20-V/H	6 WM20-I/H
19, 21	Wire from co-pilot side of instrument panel to MFD, routed top of instrument panel, inside of rack	Doors closed	32 WM19-V/A	40 WM19-I/A	13 WM21-V/H	1.3 WM21-I/H

All units are volts or amperes extrapolated to correspond with the full threat component A or H environment

Cable Bundle Currents

Table 5-5. Lightning-induced Voltages in Cable Bundles within the Mooney Fuselage

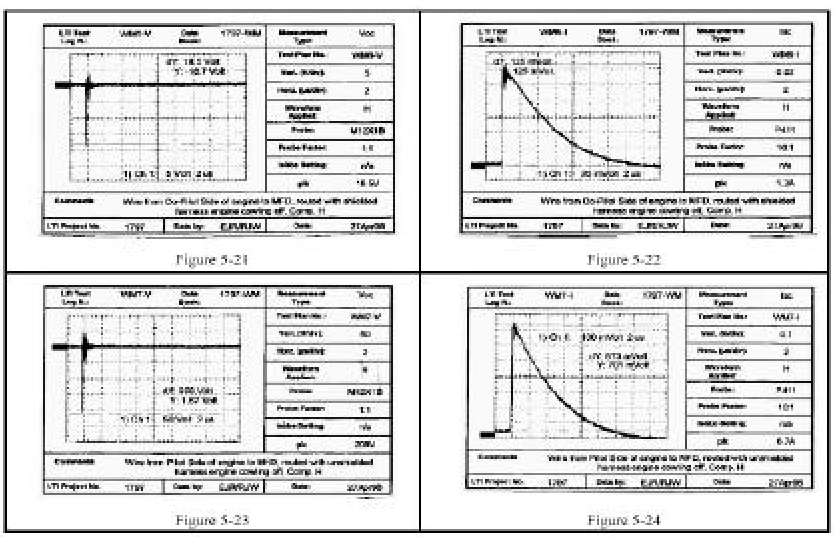
Group or Test No.	Cable Routing	Fuselage Configuration	Induced by A
			I Cable
BC-1A	VHF NAV Antenna COAX	Doors closed	220
BC-2A	Glideslope Antenna COAX	Doors closed	140
BC-3A	No. 1 VHF COMM Antenna COAX	Doors closed	20
BC-4A	No. 2 VHF COMM Antenna COAX	Doors closed	200
BC-5A	GPS No. 1 Antenna COAX	Doors closed	200
BC-6A	GPS No. 2 Antenna COAX	Doors closed	380
BC-7A	LH Cabin Wire Bundle	Doors closed	200

Engine System Circuits

Voltages and currents induced in engine-mounted circuits, with and without the engine cowling in place, were similar indicating that the **cowling affords little lightning protection** to engine electrical circuits.

This is because the lightning current enters the engine directly from the propeller, and the associated magnetic field surrounds the engine and exists between the engine and the cowling where the wiring is located.

Typical Induced transients



Coordination Among Airframer and Equipment Suppliers

Successful protection design requires careful **coordination** between the airframer and equipment suppliers, and establishment of transient control levels (**TCLs**) and corresponding equipment transient design levels (**ETDLs**), so that equipment is compatible with its installations.

TCL Selection

The TCL waveform specification may be determined by generalizing the waveforms obtained for the ATLs to match one or more of the standard transient waveforms as defined in ARP 5412 (Waveforms 1 through 5).

The TCL specification may then be determined by choosing a level that is equal to or above the level of the ATLs.

More than one TCL may be needed for a particular vehicle or system within that vehicle due to the variations of wire routing, circuit operating voltage or equipment function. TCLs are also dependent upon any shielding that may be applied to the circuit conductors.

ETDL Selection

The **ETDLs** applicable to the system establish the transient levels which the system must withstand without damage and in many cases, without being upset.

Level A, B, and C systems must withstand these pre-determined transients without damage.

ETDLs set higher than TCLs/ATLs by a margin, usually 2:1, to account for uncertainties in the verification process.

Pin-injection tests may be used to verify ability of equipment to tolerate the ETDLs.

Typical ETDLs Applicable to Avionics in Small Airplanes

Table 5-6 provides **suggested ETDLs for equipment and systems installed within a typical small airplane**.

The levels and waveforms presented have been derived from the actual transient levels measured in typical circuits within the Mooney Model 205 fuselage, together with experience from measurements of transients induced in circuits within other small airframes.

Typical ETDLs for Circuits in Small Airplanes

Table 5-6. Typical ETDLs for Equipment Interfaces within Small Airplanes

- Based on Mooney Fuselage Data, in terms of Environment Standard[1] Levels

Interfacing Harness		ETDLs Based on Component A						Multiple Burst Based on Component H			
		Waveforms		Levels		Nearest DO-160D.		Waveform		Levels	
Location	Condition	Voc	Isc	Voc	Isc	Table	Level	Voc	Isc	Voc	Isc
Entirely within Modular Protected Instrument Enclosure	Unshielded	2	1	50	100	22-3	1	3	6_H	25	5
Below Modular Instrument Enclosure	Unshielded	2	1	125	250	22-3	2	3	6_H	150	12.5
Between Modular Instrument Enclosure and Engine	Unshielded	2	1	15,000	15,000	Not available		3	6_H	25,000	1,000
	Shielded	4	5A	1,000	5,000	Not available		3	6_H	150	12.5
Between Modular Instrument Enclosure and Aft Equipment Bay	Unshielded	2	1	600	250	Not available		3	6_H	360	30
Between Modular Instrument Enclosure and Tail Area	Unshielded	2	1	600	250	Not available		3	6_H	600	12.5
Cable Bundle Currents in Fuselage	Shielded	2	1	---	1000	22-3	4	---	6_H	---	25

Table 5-7. Small Airframe Characteristics Associated with Suggested ETDLs of Table 5-6

A.	The skins of the fuselage, wings and any empennage structures that contain electrical wiring or components are fabricated of continuous solid aluminum skins of conventional thicknesses (i.e. 0.020 - 0.040 inches) or;
B.	The fuselage, wings and any empennage structures that contain electrical wiring or components are fabricated of composite materials whose entire exterior surfaces are provided with one layer of metal mesh or expanded metal foil, as described in Section 7.0, such that the internal lightning and HIRF environment within such an airframe is nearly the same as that within a metal airframe as described in (A).
C.	The engine (assuming a single engine) is attached to the airframes described in (A) or (B) by metal supports with such supports being electrically bonded to the fuselage described in (A) and (B) via direct mechanical attachment (i.e. bolts), augmented, as necessary, by electrical bond straps at each of the engine support attachments to the airframe. Also, non-conductive shock mounts should be jumpered with bond straps at all attachments.
D.	The fuselage forward bulkhead is either of conventional solid aluminum or composite provided with a metallized surface or a metal firewall.
E.	Wire harnesses installed in electromagnetically exposed areas, such as aft wing spar along the exterior surface of a wing or empennage spar, within the engine nacelle, or into a composite tip fairing are contained within a shield or conduit of substantial cross-section (i.e. equivalent to AWG No. 6 or larger).
F.	Equipment and interconnecting wiring installed on the instrument panel are contained with a modularized shielded enclosure as described in Sections 6.1.3 and 6.1.4.

HIRF and Lightning Protection Design Guidelines

Design of adequate protection against lightning and HIRF environments usually involves treatment of the **installation** of electrical and avionic equipment and associated interconnecting wiring in small airplanes as well as incorporation of certain protection features into the **equipment** itself.

The most efficient designs usually involve attention to **both** of these areas.

HIRF and Lightning Protection Features

In most cases, the protection design features that would be implemented for **HIRF** protection are compatible with **lightning** protection objectives.

Features applicable for **lightning** protection are compatible with **HIRF** protection objectives;

However, features exclusively designed for **one or the other** of these environments usually will **not provide** sufficient protection against the other environment.

Exterior Surfaces

Provide an **electrically conductive layer** on the exterior surfaces of airframe primary structures which contain avionic equipment and/or interconnecting wire harnesses, if these surfaces are not already fabricated of conventional aluminum skins.

This conductive layer may be an **expanded metal foil (EMF), woven wire mesh (WWM),** and should be co-cured with the composite laminates.

Also,

Removable access panels, doors, and engine nacelle panels/doors should be similarly protected.

Electrically connect the conductive surface layer to internal conductive elements such as the instrument panel, pedestal, cabin floor **equipotential planes** or grids, or other metal framework.

Generally, rivet patterns that provide no more than 5 kA of stroke current includes eight (8) or more small diameter rivets, or four (4) or more removable fasteners will be sufficient.

Instrument Panels

The instrument panel should ideally be made of aluminum so that all instruments, displays, and switches, etc. can be "grounded" to this panel, which forms a part of the equipotential plane.

If the panel is composite, a conductive surface may be provided with EMF. Provision should be made to connect equipment installed on the instrument panel to this EMF.

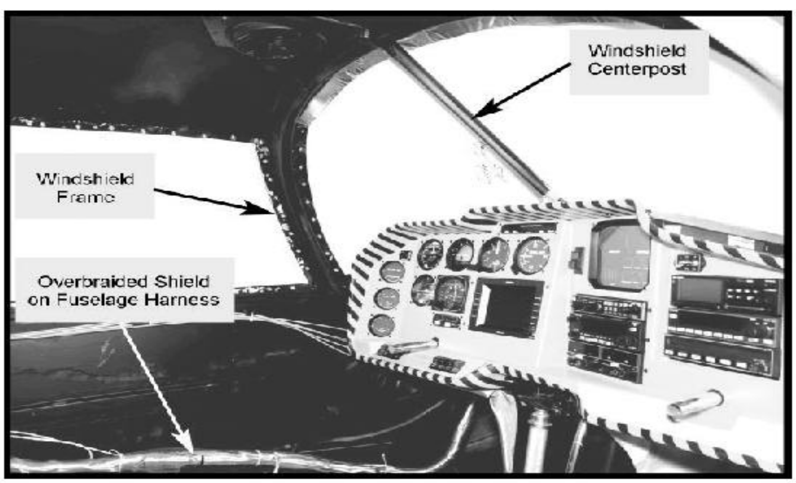
Instrument panels should be bonded to the engine firewall (in single engine aircraft), the fuselage skin conductive layer, the cockpit pedestal enclosure, the equipotential plane, or network of conductive elements inside the fuselage.

Modularized, Shielded Instrument Enclosure

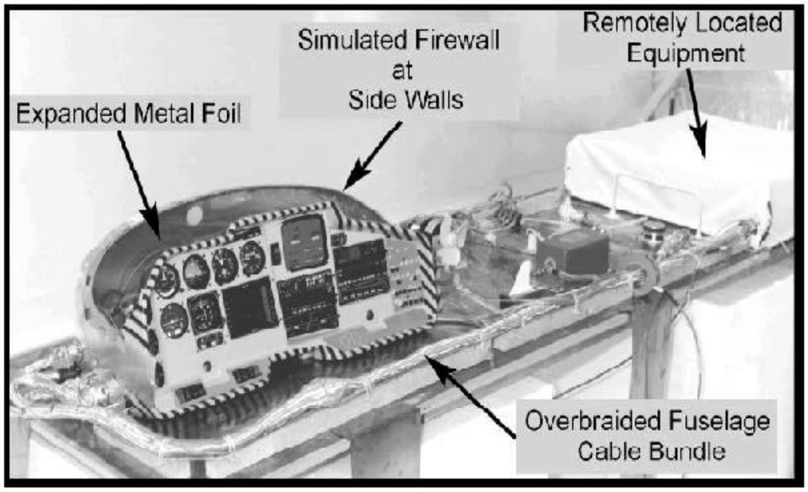
A significant reduction in the amplitudes of HIRF and lightning electromagnetic fields reaching the instrument panel equipment and wiring can be achieved by enclosing the panel and local wire harnesses within a **modularized shielded enclosure**, bounded by the panel, other elements of the equipotential plane, and a shielding enclosure covering the equipment and wire harnesses behind the panel.

The enclosure can be fabricated of EMF covered composite, or of a more rigid, self-supporting screen of aluminum or copper, which surrounds all of the instruments and displays attached to the instrument panel.

Modularized, Shielded Instrument Panel



Modularized, Shielded Instrument Panel



Circuit Design Considerations

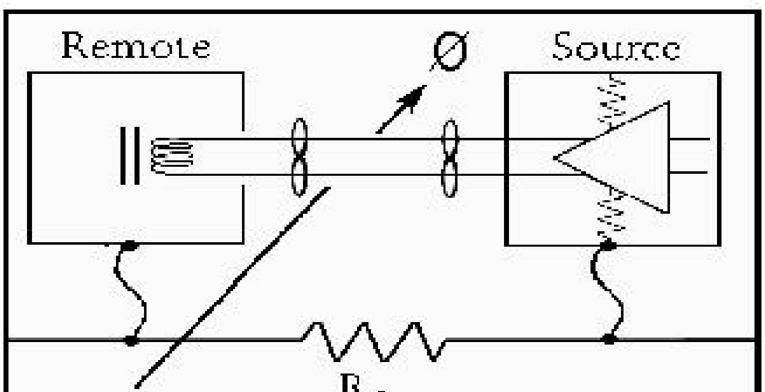


Figure 6-9 - Source unit interfacing with remote unit.

Terminal Protection Devices

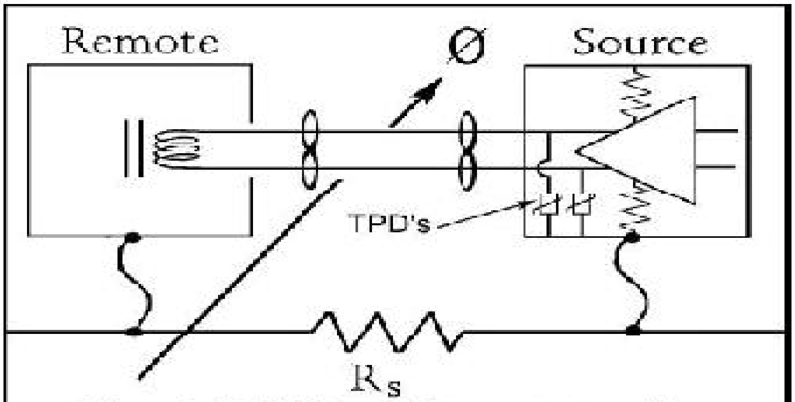


Figure 6-10 TPD's added to protect sensitive electronics in source unit.

Types of TPDs

Common TPDs are **Zener diodes, MOVs,** and **Series Resistance.**

Diodes are available in clamping voltage ratings of about 12 volts up to several hundred volts, and are useful for protection of **low voltage signal circuits**.

MOVs are available in clamping voltage ratings of several tens of volts up to hundreds of volts, and are useful for protection of **ac and dc power inputs** to electronic equipment, where higher clamping levels are needed and, also, where higher induced currents are experienced in (typically) unshielded power distribution circuits.

Series Resistance is used to limit lightning induced currents to levels that can be tolerated by protective devices, or by other components.

Protection at Power Buses

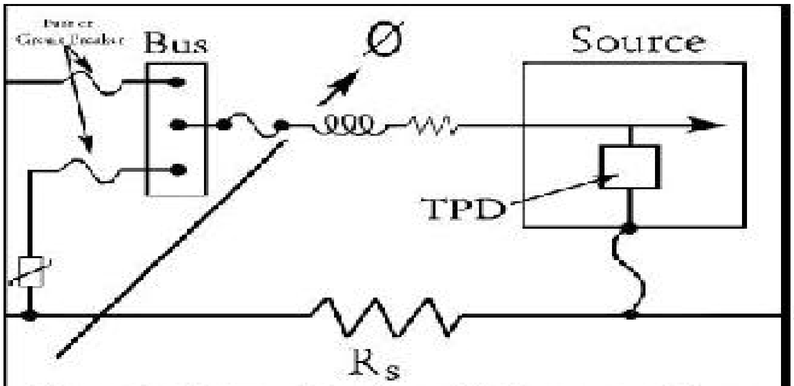


Figure 6-11 Essential unit on right is powered from 28 Vdc bus that also serves an exposed load.

Protection with Diodes and Series Resistance

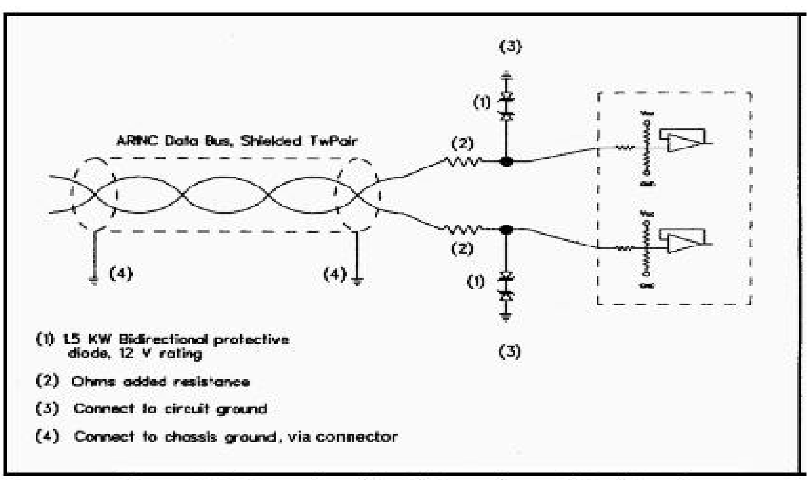


Figure 6-15. Protection of Serial Transmitter and Dual Receiver

Wire Harness Shielding

Wire harnesses **within the modularized instrument panel** enclosure will be **adequately protected** from the lightning and HIRF environments so as not to require individual or overbraid shields except those specified by the equipment manufacturers for intra-system EMI control.

Harnesses routed **from the instrument panel enclosure** to a remote avionics bay, an engine nacelle or wing area should be **provided with shields** grounded to the instrument panel enclosure or instrument cases at one end, and to the remotely located equipment cases at the other end. These shields can be brought into the modularized instrument panel enclosure, and grounded to the enclosure upon entering or at individual equipment cases.

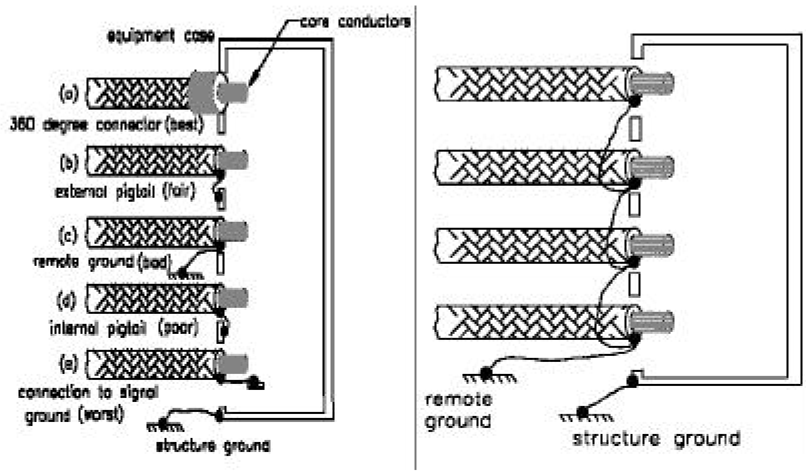
Grounding of Shields

Shields should be grounded via equipment cases ("terminated") via the backshells of connectors specifically designed for such termination.

Individual shields should be terminated at a grounding ring **within the backshell, or at strain relief clamp screws**, or other grounding provision. The connector should provide a low resistance connection to the equipment case.

If pigtails must be used, they should be as short as possible and should terminate on the connector or on the outside of the equipment case.

Grounding of Shields



Protection of Engine Circuits

Voltages and currents induced in engine circuits are especially high and these circuits, therefore, require special attention. Even shielded circuits may experience high short circuit currents.

For this reason, it is best to design all engine-mounted components so that **enclosed circuit elements are insulated from case grounds** by an amount sufficient to tolerate the anticipated Voc plus a margin, and to provide all circuit grounds and references at the instrument panel equipment and not in the engine-mounted component. In this case, no short circuit current can flow.

Shields, of course, must be grounded at both ends.

Equipment and System Verification

Verification that equipment or a system is protected against lightning-induced transients can be achieved through bench testing of equipment in accordance with recognized standards such as RTCA DO-160D Section 22.

The **Pin Injection** test of Section 22.5.1 is the most appropriate for **damage tolerance** verification.

System Functional Upset verification can be accomplished by applying the **Multiple Stroke and Multiple Burst environments** at the established ETDL levels, using the ground injection or cable induction methods described in Section 22.5.2.

Important Note:

Equipment that was previously qualified for another installation is not necessarily compatible with a new installation.

Especially if the new installation is in a composite airframe.

Ability of Equipment to tolerate the ETDLs associated with the new installation must be shown.

Also:

Test results for Equipment tested previously to **DO-160B** Section 22, or **DO-160C** Section 22 can not usually be used to show tolerance of ETDLs associated with small airplane circuits.

Test results from tests to **DO-160C (Change 2)** or **DO-160D** are applicable, especially if by the **Pin Injection Test method**, and at the appropriate Waveform Set and Level.

Tests by the **Cable Bundle Method** may also be applicable if the complete aircraft wire harness was included in the test.

Protection Design and Compliance:

- Can be more challenging for the small airplane manufacturer.
- Weight and cost of lightning (and HIRF) protection materials can be a more significant factor in a small airplane than for a large transport airplane.
- The weight "penalty" for a small airplane may reach 1% of gross weight (i.e. 30 lbs.; 15 kg.).
- For a large transport airplane the weight of lightning protection features may reach 200 lbs. (i.e. 80 kg), no more than 0.1% of gross weight.
- **But if the process is begun early and taken seriously, successful protection and compliance can be achieved.**